

APPENDIX 3C. RARE EARTH PHOSPHOR AVAILABILITY AND PRICING

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APPENDIX 3C. RARE EARTH PHOSPHOR AVAILABILITY AND PRICING

3C.1 INTRODUCTION AND PURPOSE

“Rare earth phosphors” are a key component of general service fluorescent lamps (GSFL) performance. Within GSFL, cathodes seal the inside of each lamp end emit a flow of electrons that react with mercury vapor already present in the lamp. The reaction results in the emission of invisible ultraviolet (UV) radiation. To convert the UV radiation into visible light, manufacturers coat the inside of the lamp’s glass with powdered phosphors. Phosphors are elements that fluoresce when struck by UV rays, generating visible light.

For some less efficacious GSFL, manufacturers coat the lamp with “halophosphors.” Halophosphors are more abundant and much less costly than rare earth phosphors, but also less efficient and produce a lower quality light. Coating a lamp with a layer of rare earth phosphors in addition to or instead of halophosphors can increase efficacy, while dramatically improving color quality and lumen maintenance. The blend of phosphors used by the manufacturer determines, in part, the color correlated temperature (CCT) and the color rendition index (CRI). Generally, in high-performance GSFL, manufacturers employ a blend of three rare earth phosphors: Yttrium (Y), Europium (Eu), and Terbium (Tb). Such “triband” or “triphosphor” lamps have become common practice in high performance GSFL technology.

During the comment period, some manufacturers expressed concern that stringent efficacy standards would necessitate increasing mixes of the more costly rare earth phosphors in the lamp coating. Manufacturers argued that stronger standards-induced demand would drive up the price of rare earth phosphors which are already in short supply. They added that continued growth in the compact fluorescent lamp (CFL) market will also consume future supply, jeopardizing the cost-effectiveness of the standards. Depending on the lamp type, rare earth phosphors can be the highest input cost of a GSFL.

To address these concerns, the Department of Energy (DOE) analyzed the rare earth phosphor market, seeking to understand the potential impact of the standards on supply and demand, pricing, growth, and innovation. This appendix reflects DOE’s findings.

3C.2 APPLICATIONS

Rare earths are commercially defined to include 17 elements that have similar chemical properties. Rare earths are mined primarily from bastnasite, monazite, and xenotime ores, and ion-adsorption clay. Naturally mixed in with many other elements, rare earths must be concentrated through a series of separation processes to distill the rare earth elements from the ore. The two principal means of separating rare earths are solvent extraction and ion exchange,

either of which can yield purities up to 99.999%.¹ After the mining company extracts and concentrates the rare earth elements, the mining company or a third party usually further processes it into a mixed rare earth powder.²

Rare earths have found an increasing range of practical applications in recent decades. Phosphors are a subgroup of the rare earth element market. Aside from phosphor applications, rare earths are used in automotive catalysts, metals and magnets, petroleum catalysts, glass polishing, and ceramics. Currently, there are few, if any, suitable substitutes in most applications.

Various sources estimate that phosphors represent 4 percent to 15 percent of the rare earth market by quantity; the most recent estimates typically range between 7 percent and 11 percent.³ Within this phosphor subgroup, there are three main applications: televisions (plasma, LCD and cathode ray tube), tri-phosphor fluorescent lamps, and x-ray intensifying screens.

The most important rare earth phosphors are Y, Eu, and Tb, which are used to emit light at the wavelengths (and therefore colors) to which our eyes are most sensitive. These three elements are used in different combinations of phosphors to emit blue, red, and green light. Tb is used for green light, while Eu and Y are used for blue and red. Very high levels of purity are necessary for these phosphors in lighting applications, which increases the cost to lamp manufacturers. Eu and Tb must be greater than 99.99% pure and Y 99.999%.

3C.3 RARE EARTH MARKET

Historically, unstable supply and demand and significant price fluctuations have been the norm in the rare earth market. The 1980s saw rapidly increasing demand, followed by substantial oversupply in the 1990s.⁴ Prior to China's entry into the market in the early 1990s, most production came from the United States. By the late 1990s, China's low-cost supply had driven down prices. China's market power contributed to the dramatic changes the market has since experienced. Most recently, limited supply and demand growth has driven prices of Eu, Y, and Tb up sharply after years of oversupply and relatively lower prices characterized the market.

3C.3.1 Market Size

A Roskill report estimates the overall value of the rare earth market at \$1.25 billion.⁵ According to a Rhodia presentation, the 2007 phosphor portion of the rare earth market totaled about \$670 million⁶, while an earlier Roskill report put the 2000 total rare earth phosphor market at \$300 million.⁷ That implies a 12.2 percent compounded annual growth rate (CAGR) in the rare earth phosphor market from 2000 to 2007.

Of Rhodia's \$670 million estimate for the 2007 phosphor market, lamps accounted for \$355 million (\$30 million of which was halophosphor). The presentation also predicted the

phosphor market will grow to \$925 million by 2012, a 6.8 percent CAGR. Lamps will account for approximately 60 percent of that growth.⁸

The total rare earth oxide supply (market size is generally defined in terms of oxides) was 142,000 metric tons in 2007. Europium, terbium, and yttrium phosphor was 300, 300 and 4,500 metric tons, respectively.⁹

3C.3.2 Supply

Most rare earth elements are not actually rare. However, large, economically viable deposits of important rare earths (like Terbium and Europium) are more scarce because they are mixed with other minerals and require a costly purification process to isolate. Portions of different rare earths vary greatly in deposits. These ratios often do not correspond to the ratios of rare-earth phosphor required in their applications. Therefore, to get enough of the rarer, more important elements, mining companies must produce large amounts of more widespread metals.¹⁰

China now dominates rare earth supply, accounting for more than 95 percent of world's rare earth production.¹¹ That market position, coupled with Chinese policy changes, has created significant potential for supply disruptions in the short run.

Beginning early this decade, China began to take steps to curb production of rare earths and thereby increase prices. Additionally, the desire to preserve the resource and address environmental concerns has constrained Chinese supply. Recently, the country instituted mining quotas, which have been continually reduced. "Over the 3 years to 2007, China reduced the annual export quota from 48,500t REO [rare earth oxide] to 42,500t REO - equivalent to an average reduction of 3.5% [per year]. If this trend continues at the same rate, exports will total 39,000t REO in 2010, compared with forecast non-Chinese consumption of 50,000t."¹² In the meantime, short-term production outside China has not increased to make up for the latter's lower output and the increasing worldwide demand. Current production of the key phosphors terbium and europium is not sufficient to meet near-term consumption demand.¹³ This has spurred a number of mining projects to take shape around the world, as higher prices have enticed greater market entry.

3C.3.3 Long-Term Supply

While China has been more restrictive in its export policies, the existing Chinese reserves represent a small portion of all the undeveloped reserves worldwide. According to the U.S. Geological Survey, "Undiscovered resources are thought to be very large relative to expected demand."¹⁴ The USGS estimated that 88 million tons of proven economically viable reserves of rare earths exist, 61 million tons of which are outside China.¹⁵ For perspective, Rhodia expects global supply to be 190,000 tons by 2010, up from an estimated 142,000 tons in 2007.¹⁶ The USGS concludes that "world reserves are sufficient to meet forecast world consumption well into the next decade. Several very large rare-earth deposits in Australia and China have yet to be

fully developed.” Rare earths price surges and the need for non-Chinese production has driven increased interest in new rare earth mining and production projects. Several projects listed below are in early phases of development around the world. Many of these projects have proven reserves that are many times larger than China’s recent export quotas.

Molycorp, Inc.’s rare earth mine in Mountain Pass, CA is an example of rare earth production in response to recent change in prices. Just 10 years after generating more than 40 percent of worldwide rare earths revenue, the mine shut down operations in 2000 “due to record lows” of rare earth prices.¹⁷ The mine only remained open for the concentration, purification, and sale of its previously mined stocks.¹⁸ In 2007, amid increasing rare earth prices, the company announced it planned to resume mining operations with sales of rare earths beginning as early as 2008.¹⁹ The mine has some 20 million metric tons of rare earth reserves (more than 400 times China’s most current export quota)²⁰

Australia also has the potential to become a major rare earth supplier. Lynas Corporation’s Mt. Weld project in Western Australia is expected to ramp to full capacity by 2011.²¹ Lynas’ planned production is 21,000 tons per year of rare earth oxide, about 7 percent to 9 percent of total 2007 global supply based on various estimates.^{22,23} The total resources available at the mine, measured by rare earth oxide, are 917,000 metric tons (769,000 tons of which is proven and economically viable).²⁴

Also in Australia, Afurara Resources’ Nolans project has identified 577,000 metric tons of indicated and inferred REO. The company plans to reach 50 percent production capacity by 2011 and full capacity, or 20,000 metric tons, by 2013. That amounts to roughly 10 percent of worldwide supply at that time.²⁵ Alkane Exploration Ltd.’s Dubbo Zirconia Project in Australia may begin producing Yttrium by mid-2010. A feasibility study indicated an annual yield of 1,200 tons of Yttrium and other rare earths is possible.²⁶

In Canada, Avalon Ventures Ltd.’s Thor Lake site may be able to produce 4,000 to 5,000 metric tons of REO per year.²⁷ The deposit appears to be relatively rich in terbium and europium. Great Western Minerals Group has a rare earth deposit in Saskatchewan at Hoidas Lake with REO measured reserves of some 3,500 tons and indicated reserves of another 12,000 tons.

3C.3.4 Demand

While supply capacity appears restricted in the near term, demand for rare earth phosphors is projected to grow rapidly. Macro trends towards energy efficiency and larger display technologies have driven growth in phosphor demand. Displaybank projects the number of LCD and plasma televisions to grow 12 percent to 13 percent annually from 2007 to 2015, with the average panel size growing 15 percent. The growth in CFLs is also contributing to phosphor demand. Lynas Corporation projects demand for rare earth phosphors for use in CFLs to grow from 1,600 tons in 2004 to 3,779 tons by 2010, or 15 percent annually.²⁸ Rare earth demand from China itself is also sapping supply, growing at 25 percent annually from 2004 to 2007, according to Roskill.²⁹

A Rhodia presentation forecasted Eu, Y, and Tb demand to grow 50 percent, 47 percent and 40 percent, respectively, from 2007 to 2012. The table below represents Rhodia's demand and supply projections for each of the key phosphors.³⁰

Table 3B.3.1 Supply and Demand Projection for Key Phosphors

Element	Year	Supply	Demand
		In Metric Tons	
Eu	2007	300	300
	2012	450	450-500
Tb	2007	300	300
	2012	420	420
Y	2007	11,700	7,500
	2012	14,000	10,600

3C.3.5 Pricing

Historically, prices for rare earths, particularly the key three phosphors in lamps, have been extremely volatile. Recent price estimates have already proven well off the mark. Tb, Eu, and Y have seen dramatic price increases recently, with Tb in the shortest supply and the most expensive. Similarly, Yttrium is the most abundant and the cheapest. DOE consulted a range of industry sources to determine the appropriate market prices for the three phosphors.

The key phosphors have all experienced dramatic price increases recently. Chinese policy of limiting supply, environmental concerns, increases in tariffs and others taxes, demand growth, and speculation have all contributed to price increases. According to Rhodia, the prices of Y, Tb and Eu have increased roughly 45 percent, 420 percent and 53 percent, respectively, since 2000. Much of the price increases occurred in the last two years.³¹ Additionally, in June 2006 China established a 10 percent tariff on rare earths. For key phosphors, the tariff is now 25 percent.

3C.4 PHOSPHOR SUPPLY IMPACTS

To analyze the impact of efficacy standards on manufacturer phosphor requirements compared to total rare-earth phosphor supply, DOE determined the increased national need for rare-earth phosphors that would result from higher GSFL efficacy standards. To calculate this increased demand, DOE first estimated the mass of each rare earth phosphor used in each lamp type (e.g., 4-foot T8 medium bipin) for three series of rare-earth phosphor lamps— 700, standard 800, and high-performance 800. Next, using its shipments analysis, DOE estimated the total quantities of each phosphor required to meet the shipment demands. DOE compared these results (for 2012) to industry projections of phosphor demand to evaluate how standards may affect the overall supply-demand balance.

In interviews, manufacturers provided estimates for the mass of rare earth phosphor per high performance 800-series 4-foot T8 medium bipin (MBP) lamp. They also reported the quantity of rare earth phosphor that is necessary to improve a 700-series lamp to the level of a high performance 800-series lamp. By using the relative efficacies of the 700 series, 800 series, and high performance 800 series and industry curves relating phosphor thickness to efficacy, DOE derived estimates for the amount of rare earth phosphor used in the three series of 4-foot T8 MBP lamps. DOE also estimated (based on manufacturer interviews) the relative proportions (by weight) of each phosphor used in the lamp coating (Eu, Tb, and Y). DOE extrapolated the estimated 4-foot MBP rare-earth phosphor requirements to 8-foot single pin (SP) slimline, 8-foot recessed double contact (RDC) high output (HO), 4-foot miniature bipin (MiniBP) standard output (SO), and 4-foot MiniBP HO lamps using relative lamp surface areas.

DOE's analysis evaluated the impact of each trial standard level on the phosphor markets. DOE estimates that raising the minimum efficacy requirements for GSFL would increase the global demand of these phosphors. DOE expects 2012 Tb demand to increase by up to 31 percent under amended energy conservation standards relative to the base case. DOE estimates that Eu demand could increase by 10 percent, while Y demand would likely increase marginally. These estimates reflect the upper bound of demand increases over all trial standard levels and shipment scenarios. For further detail on trial standard levels and GSFL shipment forecasts, see chapter 9 and chapter 10 of this TSD, respectively.

3C.5 PHOSPHOR PRICE IMPACTS

Given the historically volatile prices of rare-earth phosphors and the unpredictable future determinants of supply and demand (such as Chinese policy, additional mining operations, and future technological changes), DOE has not developed supply and demand curves to estimate future phosphor prices. However, DOE recognizes significant price increases are possible given the expected increase in demand, particularly for Tb and Eu. Therefore, to analyze the impact of higher phosphor prices on the consumer, DOE also conducted a sensitivity analysis to address the potential increases in end-user lamp prices attributable to greater phosphor input costs. That is, DOE compares the life-cycle cost (LCC) savings due to purchasing higher efficacy GSFL (as calculated in chapter 8) to LCC savings under scenario with higher phosphor prices.

As discussed earlier, DOE determined the quantity of each rare-earth phosphor required to manufacture each phosphor series of GSFL. DOE then determined the cost of the rare earth phosphors to the manufacturers for each lamp type, considering the quantity of each phosphor required and the current estimated cost of each phosphor type. Next, by applying manufacturer and retail markups, DOE analyzes how an increase in phosphor prices may affect LCC savings for a consumer of each lamp type.

4-foot T8 MBP lamps account for the majority of phosphor costs over the analysis period at high standard levels. For this product class, DOE calculated that rare earth phosphor costs are approximately \$0.52 per high performance 800 series T8 lamp at current phosphor prices. Using

a combined manufacturer and retail markup of 2.28, DOE estimates rare earth phosphors account for approximately \$1.19 of the per-unit cost to the consumer. Because purchasers of all 4-foot MBP baseline lamps for all events in the commercial sector show LCC savings of at least \$10.69 upon purchasing high performance 800 series lamps, phosphor prices could increase 9 times (and more in most cases) before commercial consumers would experience negative LCC savings for this product class. In the residential sector, for events that show positive LCC savings in the base case, consumers could sustain even larger phosphor price increases before they experience negative LCC savings.

For 8-foot SP slimline lamps, phosphor prices could increase by a minimum of 400 percent before any commercial or residential consumers experienced negative LCC savings in almost all non-voluntary events. The only exception is for the 60W T12 baseline in the lamp failure event. In general, phosphor prices for this product class could increase by at least 7.5 times before most baseline lamps in most events would begin to show negative LCC savings.

For 8-foot RDC HO lamps, phosphor prices could increase by more than 450 percent before commercial or residential consumers experienced negative LCC savings in all events for the 110W T12 baseline lamp. However, for 95W baseline lamp, the lamp failure and ballast replacement events already show negative LCC savings. Phosphor prices could increase 7.5 times before LCC savings in any other events would become negative.

For 4-foot T5 MiniBP SO lamps, phosphor prices could increase more than 250 percent before any commercial or residential consumer experienced negative LCC savings for any event. For 4-foot T5 MiniBP HO lamps, where LCC savings are positive at current phosphor prices for all events except lamp failure, only a 90-fold increase in phosphor prices could jeopardize positive LCC savings.

3C.6 CONCLUSIONS

While higher-efficacy standards on GSFL may require more rare earth phosphors, the above analysis indicates that there would be sufficient supply to meet the increased demand. Large deposits of rare earths exist outside of China, notably in Canada and Australia, which could make up for any supply shortage induced by amended GSFL energy conservation standards. In fact, restrictive Chinese export policies, which have put upward pressure on phosphor prices, have already spurred additional mining projects globally. If prices continue to climb, DOE expects the economics of mining rare earths to encourage more projects, and make less concentrated rare earth deposits economically viable, which will increase supply. Additionally, research continues on acceptable substitutes and more effective combinations of rare earth phosphors for use in energy efficient lamps and televisions. There is also a movement to recycle phosphorous materials to meet some of the growing demand. While there has been recent price volatility in the rare-earth phosphor market, the above analysis shows that the price of phosphor could continue to increase and most consumers who, under current phosphor prices,

experience positive LCC savings would continue to do so. For these reasons, DOE does not believe standards, and their potential impact on phosphor prices, will affect product availability.

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